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# The cost-effectiveness of banning highly hazardous pesticides to prevent suicides due to pesticide self-ingestion across 14 countries: an economic modelling study

Y Y Lee, D Chisholm, M Eddleston, D Gunnell, A Fleischmann, F Konradsen, M Y Bertram, C Mihalopoulos, R Brown, D F Santomauro, J Schess, M van Ommeren



## Summary

**Background** Reducing suicides is a key Sustainable Development Goal target for improving global health. Highly hazardous pesticides are among the leading causes of death by suicide in low-income and middle-income countries. National bans of acutely toxic highly hazardous pesticides have led to substantial reductions in pesticide-attributable suicides across several countries. This study evaluated the cost-effectiveness of implementing national bans of highly hazardous pesticides to reduce the burden of pesticide suicides.

**Methods** A Markov model was developed to examine the costs and health effects of implementing a national ban of highly hazardous pesticides to prevent suicides due to pesticide self-poisoning, compared with a null comparator. We used WHO cost-effectiveness and strategic planning (WHO-CHOICE) methods to estimate pesticide-attributable suicide rates for 100 years from 2017. Country-specific costs were obtained from the WHO-CHOICE database and denominated in 2017 international dollars (I\$), discounted at a 3% annual rate, and health effects were measured in healthy life-years gained (HLYGs). We used a demographic projection model beginning with the country population in the baseline year (2017), split by 1-year age group and sex. Country-specific data on overall suicide rates were obtained for 2017 by age and sex from the Global Burden of Disease Study 2017 Data Resources. The analysis involved 14 countries spanning low-income to high-income settings, and cost-effectiveness ratios were analysed at the country-specific level and aggregated according to country income group and the proportion of suicides due to pesticides.

**Findings** Banning highly hazardous pesticides across the 14 countries studied could result in about 28 000 (95% uncertainty interval [UI] 24 000–32 000) fewer suicide deaths each year at an annual cost of I\$0·007 per capita (95% UI 0·006–0·008). In the population-standardised results for the base case analysis, national bans produced cost-effectiveness ratios of \$94 per HLYG (95% UI 73–123) across low-income and lower-middle-income countries and \$237 per HLYG (95% UI 191–303) across upper-middle-income and high-income countries. Bans were more cost-effective in countries where a high proportion of suicides are attributable to pesticide self-poisoning, reaching a cost-effectiveness ratio of \$75 per HLYG (95% UI 58–99) in two countries with proportions of more than 30%.

**Interpretation** National bans of highly hazardous pesticides are a potentially cost-effective and affordable intervention for reducing suicide deaths in countries with a high burden of suicides attributable to pesticides. However, our study findings are limited by imperfect data and assumptions that could be improved upon by future studies.

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## Introduction

Suicide is a major global public health issue, resulting in 800 000 deaths every year across the world.<sup>1</sup> The Sustainable Development Goals (SDGs) have made reducing suicide a key target for improving global health. Pesticide self-poisoning makes up 110 000–168 000 (14–20%) of global suicides<sup>2</sup> and is particularly common in low-income and middle-income countries (LMICs) where small-scale farming allows easy access to highly hazardous pesticides among households and communities.<sup>3</sup> Some highly hazardous pesticides are acutely lethal and can cause

severe and irreversible harms to health (with WHO hazard classifications of 1a, 1b, and sometimes 2).<sup>4–7</sup> The case fatality for poisoning with some highly hazardous pesticides, such as 20% paraquat solutions and 56% aluminium phosphide tablets, often exceeds 50%,<sup>8,9</sup> making it comparable to other high-lethality suicide methods, such as firearms and hanging.<sup>10,11</sup>

Studies from Sri Lanka<sup>12</sup> and China<sup>13</sup> have shown that many acts of pesticide self-poisoning are impulsive, involving less than 30 minutes of planning. The poison used by individuals was determined by what was readily

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## Research in context

### Evidence before this study

Suicide by pesticide ingestion is one of the most common methods of suicide in low-income and middle-income countries, with an estimated 110 000–168 000 deaths annually. Restricting access to commonly used, highly lethal suicide methods is one of the most effective strategies for reducing suicide. A 2017 systematic review reported that national bans of pesticides commonly used for suicide were followed by reductions in pesticide-attributable suicides among five of the six countries or territories where these had been studied, and reductions in overall suicide mortality in three countries (Bangladesh, South Korea, and Sri Lanka). The cost-effectiveness of this approach to suicide prevention has not been evaluated from a global perspective.

### Added value of this study

This modelled economic evaluation is, to our knowledge, the first multi-country analysis to examine the cost-effectiveness of enacting nationwide bans of highly hazardous pesticides to reduce suicide mortality attributable to pesticide self-poisoning. The model estimated that banning these pesticides across 14 countries could result in up to 361 000 (95% uncertainty interval [UI] 307 000–419 000) fewer suicide deaths by 2030, which is a potential 6.5% (95% UI 5.5–7.4)

reduction at an annual cost of \$0.007 per capita (95% UI 0.006–0.008). This reduction is about 20% of target 3.4 of the Sustainable Development Goals, which is to reduce premature mortality from non-communicable diseases by one third. Bans of highly hazardous pesticides were found to be highly cost-effective in low-income and lower-middle-income countries, with a cost-effectiveness ratio below \$100 (international dollars) per healthy life-year gained, and were most cost-effective among countries with a high proportion of suicides due to pesticides.

### Implications of all the available evidence

National bans of highly hazardous pesticides can produce substantial, cost-effective reductions in suicide mortality in countries with a high burden of suicides attributable to pesticide. Evidence generated by this study can inform the implementation and advocacy of The International Code of Conduct on Pesticide Management (jointly published by WHO and the Food and Agriculture Organization of the UN in 2014), as well as future policy guidance on highly hazardous pesticides. Study findings are limited by imperfect data and assumptions. Further research is required to quantify effects on substitution of means and agricultural productivity.

available in a person's home or purchased from a local shop, with little regard for its toxicity.<sup>12</sup> In other words, people were not deliberately selecting highly hazardous pesticides to ensure a high risk of death.

Restricting access to commonly used, high-lethality suicide methods—a form of means restriction—is one of the few effective approaches to preventing suicide.<sup>1,14</sup> Suicides caused by ingestion of highly hazardous pesticides are preventable.<sup>1,6,15</sup> Reducing access to such pesticides results in people attempting suicide using less fatal means, markedly increasing their chances of survival. Suicidal impulses are frequently transient, and more than 90% of people who survive a suicide attempt do not go on to die from suicide later in life.<sup>16</sup>

Studies of nationwide bans of acutely toxic pesticides provide data to support the means restriction approach. Bans of just a few highly hazardous pesticides resulted in communities having access to less toxic pesticides and led to sharp reductions in overall suicide rates in Sri Lanka (figure 1),<sup>17</sup> Bangladesh, and South Korea.<sup>15</sup> These pesticide bans did not prevent people from attempting suicide; they simply made subsequent suicide attempts much less lethal, thereby lowering the suicide rate. Empirical evidence from these countries also shows that such bans do not necessarily lead to reductions in agricultural productivity (ie, there were no discernible subsequent decreases in crop yields).<sup>18–21</sup> The International Code of Conduct on Pesticide Management,<sup>4</sup> produced by the UN Food and Agriculture Organization (FAO) and

WHO, recommends that highly hazardous pesticides should be removed from agriculture in LMICs where they cannot be stored or used without hazard.

In May, 2019, the 72nd World Health Assembly passed a resolution requesting the WHO Director-General to prepare and update a menu of policy options and cost-effective interventions for improving mental health.<sup>22</sup> This list will inform an update of the WHO comprehensive mental health action plan 2013–20,<sup>23</sup> which seeks to facilitate the achievement of SDG target 3.4 by 2030: to reduce by one third premature mortality from non-communicable diseases (NCDs) and promote mental wellbeing.<sup>24</sup> The current study presents the results of an economic evaluation of the cost-effectiveness of implementing nationwide bans of highly hazardous pesticides to reduce suicide mortality due to pesticide self-poisoning across different country contexts.

## Methods

### Data sources and assumptions

This modelling study adopted a health systems perspective that aligns with WHO cost-effectiveness and strategic planning (WHO-CHOICE) methods.<sup>25</sup> We briefly describe here the analytic choices deriving from WHO-CHOICE methods; more detail of their background and rationale is in the appendix (pp 2–3). A Markov model was developed in Microsoft Excel 2013 to examine the costs and health effects of implementing a

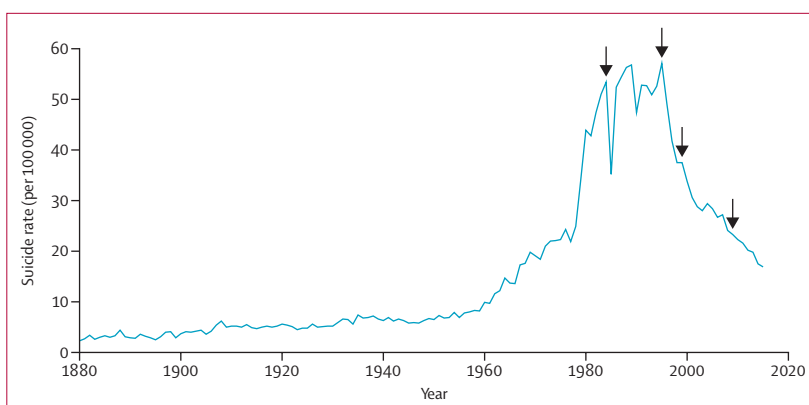
For WHO-CHOICE see <https://www.who.int/choice/en/>

See Online for appendix

national ban of highly hazardous pesticides to prevent suicides due to pesticide self-poisoning. Such a ban would generally involve specifying a list of highly hazardous pesticides that comprise the major causes of pesticide suicides in a given country. Analyses were done on a group of 20 countries from different regions and income levels, which together account for 63% of the world population and 65% of the global burden of disease. These countries were chosen on the basis of a previous WHO cost-effectiveness study<sup>26</sup> to identify best-buys for NCDs, which presents its results for two country income groups: low-income and lower-middle-income countries (LLMICs) and upper-middle-income and high-income countries (UMHICs). Table 1 shows the proportion of suicides due to pesticide self-poisoning across the 20 countries. Six of these countries (Germany, Japan, Russia, Turkey, Ukraine, and the USA) were excluded from subsequent economic analysis following advice from an international expert panel to limit the analytic scope to countries with more than 2% of suicides attributable to pesticide self-poisoning. The 2% threshold was based on the proportion of suicides due to paracetamol poisoning in England and Wales when paracetamol regulations were enacted across the UK in the late 1990s as a suicide prevention measure.<sup>30</sup> It was judged to be a policy-relevant threshold in the absence of better corroborating data.

The costs and health effects accruing in an intervention scenario (in which highly hazardous pesticide bans are enacted) were compared with those in a null comparator. The intervention costing consequently assumed that no pesticide regulatory mechanisms were in place and that no previous pesticide bans had been implemented, as per WHO-CHOICE methods. Country-specific costs were obtained from the WHO-CHOICE database and denominated in 2017 international dollars (I\$). In line with WHO-CHOICE methods, all costs were discounted at a 3% annual rate, with no discounting applied to health effects, whereas health-care cost savings and changes in workforce productivity were out of the scope of the analysis.<sup>25</sup> The model did not evaluate changes in agricultural productivity because these occur outside the perspective of the health system, although empirical evidence from Sri Lanka,<sup>20,31</sup> Bangladesh,<sup>19</sup> India,<sup>21</sup> and South Korea<sup>18</sup> shows no discernible decrease in crop yields following national bans of highly hazardous pesticides. The health effects of interventions were measured in healthy life-years gained (HLYGs). Costs and health effects were analysed for each of the 14 countries at the country-specific level, and the final results were aggregated according to country income group (ie, LLMICs and UMHICs) and the proportion of suicides due to pesticides (ie, 2–9%, 10–19%, 20–29%, and >30%).

The modelling approach was refined following consultations with an international expert panel who provided in-person feedback at a meeting at WHO headquarters in Geneva on Aug 20, 2019, and



**Figure 1: Overall suicide rate in Sri Lanka, 1880–2015**

Arrows show timing of pesticide bans in 1984 (parathion and methylparathion), 1995 (all remaining WHO class 1 toxicity pesticides, including methamidophos and monocrotophos), 1998 (endosulfan), and 2008 (dimethoate, fenthion, and paraquat). Suicide data were obtained from police records. Reproduced with permission from Knipe et al.<sup>17</sup>

through email communications. This study adhered to Consolidated Health Economic Evaluation Reporting Standards (CHEERS) (appendix pp 4–6).<sup>32</sup>

The demographic projection model begins with the country population in the baseline year (2017), split by 1-year age group and sex (figure 2). Flows into and out of each age-sex cohort were simulated for each subsequent year for 100 years. These flows included outflows due to death (from suicide or other causes), inflows in the 0–1 year cohort due to new births, and net migration. Data on the 2017 country population (from 0 to ≥80 years) and corresponding age-specific mortality rates over the 100-year time horizon were obtained from OneHealth Tool. Data on new births and net migration were obtained from the UN World Population Prospects 2017 report,<sup>33</sup> and all demographic projections were validated against estimates from that report. Further details on demographic projections are in the appendix (pp 7–11).

### Intervention effect size

The intervention effect size was based on a systematic review<sup>15</sup> of international studies examining the effect of national bans on the sale or import of specific pesticides in reducing suicide mortality from pesticide self-poisoning. Briefly, this review identified 12 studies of bans implemented across six countries or territories: Bangladesh, Chinese Taipei, Crete, Jordan, South Korea, and Sri Lanka. National bans of the most commonly ingested pesticides led to reductions in pesticide suicides in all countries or territories except Crete. Furthermore, overall suicide mortality decreased in three countries (Bangladesh, South Korea, and Sri Lanka). A study<sup>21</sup> published after the systematic review similarly found that a nationwide ban of endosulfan across India was followed by declines in overall and pesticide-related suicides. On the basis of these findings and advice from the international expert panel, a gradual linear increase in

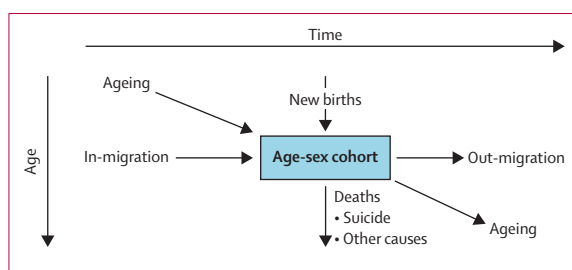
For OneHealth Tool see  
[https://www.avenirhealth.org/  
software-onehealth.php](https://www.avenirhealth.org/software-onehealth.php)

	Overall suicide rate in 2017 (per 100 000)	Proportion of suicides attributable to pesticide self-poisoning (uncertainty range)*	Source
<b>LLMICs</b>			
Bangladesh	Males: 5.88; females: 6.02	Both: 20.9% (range 10.5–31.4)	2014 country-specific estimate from Chowdhury et al; <sup>19</sup> assume 50% uncertainty
Ethiopia	Males: 7.34; females: 2.54	Both: 24.0% (range 12.0–36.0)	AFRO regional estimate; <sup>27†</sup> assume 50% uncertainty
Guatemala	Males: 9.21; females: 2.32	Males: 16.8% (n=352); females: 27.1% (n=144)	2015 estimate from WHO mortality database
India	Males: 16.97; females: 13.49	Males: 34.0% (range 23.8–44.2); females: 29.0% (range 20.3–37.7)	Adjusted‡ country-specific estimate from Patel et al <sup>18</sup>
Indonesia	Males: 4.63; females: 1.47	Both: 11.3% (range 5.7–17.0)	SEARO regional estimate; <sup>2</sup> assume 50% uncertainty
Nigeria	Males: 5.40; females: 2.53	Both: 24.0% (range 12.0–36.0)	AFRO regional estimate; <sup>27†</sup> assume 50% uncertainty
Pakistan	Males: 3.97; females: 4.53	Both: 7.1% (range 3.6–10.7)	EMRO regional estimate; <sup>2</sup> assume 50% uncertainty
Philippines	Males: 8.16; females: 2.53	Males: 3.4% (n=1411); females: 4.4% (n=409)	2008 estimate from WHO mortality database
Ukraine (out of scope)§	Males: 56.66; females: 8.38	Both: 0.9% (range 0.5–1.4)	EURO regional estimate; <sup>2</sup> assume 50% uncertainty
Vietnam	Males: 10.67; females: 4.90	Both: 11.3% (range 5.7–17.0)	SEARO regional estimate; <sup>2</sup> assume 50% uncertainty
<b>UMHICs</b>			
China	Males: 10.67; females: 7.47	Both: 49.0% (n=120 730)	2013 country-specific estimate from Page et al <sup>19</sup>
Germany (out of scope)§	Males: 22.06; females: 7.49	Males: 0.2% (n=7397); females: 0.1% (n=2681)	2015 estimate from WHO mortality database
Iran	Males: 8.29; females: 3.25	Males: 5.8% (n=1669); females: 7.1% (n=706)	2015 estimate from WHO mortality database
Japan (out of scope)§	Males: 31.87; females: 13.50	Males: 0.8% (n=16 202); females: 1.4% (n=6950)	2015 estimate from WHO mortality database
Mexico	Males: 10.10; females: 2.13	Males: 3.0% (n=5031); females: 7.0% (n=1251)	2015 estimate from WHO mortality database
Russia (out of scope)§	Males: 52.88; females: 10.18	Both: 1.7% (range 0.9–2.6)	HIC regional estimate; <sup>2</sup> assume 50% uncertainty
South Africa	Males: 18.35; females: 4.59	Males: 2.9% (n=377); females: 6.7% (n=105)	2015 estimate from WHO mortality database
Thailand	Males: 20.15; females: 5.02	Males: 15.5% (n=3283); females: 22.4% (n=848)	2016 estimate from WHO mortality database
Turkey (out of scope)§	Males: 5.67; females: 1.43	Males: 0.1% (n=1135); females: 0.8% (n=397)	2015 estimate from WHO mortality database
USA (out of scope)§	Males: 23.61; females: 6.70	Males: 0.0% (n=33 959); females: 0.1% (n=10 186)	2015 estimate from WHO mortality database

LLMICs=low-income and lower-middle-income countries. AFRO=African region. SEARO=southeast Asian region. EMRO=eastern Mediterranean region. EURO=European region. UMHICs=upper-middle-income and high-income countries. HIC=high-income country. \*In the uncertainty analysis, proportions with uncertainty ranges denoted by range were modelled using the PERT distribution, with arguments comprising the minimum, most likely, and maximum values. Conversely, proportions with uncertainty ranges denoted by N were modelled using the beta distribution (ie, the conjugate prior of the binomial distribution). †AFRO regional estimates were from the 2007 systematic review by Gunnell et al<sup>27</sup> instead of the 2017 systematic review by Mew et al.<sup>2</sup> The 2017 AFRO regional estimate was likely to be a significant underestimate given that data were only available for South Africa and Mauritius, which were not representative of the broader AFRO region. The previous 2007 AFRO regional estimate was estimated to be between 15% and 33%, the average of which was used for the current study. ‡The original study was based on data from a 2001–03 survey that estimated the proportion of suicides due to pesticides in India was 39% among males and 35% among females. These estimates were adjusted downwards based on the expert opinion of two study authors (ME and DG) to account for declining trends in the proportion of suicides due to pesticides, which have been observed in national police report data (ie, the Government of India National Crime Records Bureau). §Six out-of-scope countries were excluded from the economic evaluation because they involved a proportion of suicides due to pesticide self-poisoning that was less than 2% (ie, the threshold below which it would not be worthwhile to implement a national ban of highly hazardous pesticides).

**Table 1: Overall suicide rates and the proportion of suicides attributable to pesticide self-poisoning across 20 countries**

For the WHO mortality database  
see [https://www.who.int/healthinfo/mortality\\_data/en/](https://www.who.int/healthinfo/mortality_data/en/)



**Figure 2: Overview of the demographic projection model**

intervention effect size was applied to the pesticide suicide rate (starting from a rate ratio [RR] of 1.00 at baseline, up to a final RR of 0.65 in year 5). This gradual increase accounts for the lag between an initial ban and the time it takes to exhaust the available stock of banned pesticides. The final RR at year 5 was assumed to be maintained over the remaining 100 years of the model (on the assumption

that once a pesticide has been removed from common usage, it will not be reintroduced). Post-intervention changes to the overall suicide rate reflected the aforementioned decreases in pesticide suicides, offset by a small increase in non-pesticide suicides to account for means substitution (ie, the use of alternative suicide methods following pesticide restrictions). The intervention effect size is further described in the appendix (pp 7–13).

### Health effect modelling

In the model, each age-sex cohort transitioned between two health states over time (ie, alive and dead), due either to death due to suicide or death due to other causes. The main outcome following a national ban on highly hazardous pesticides was a reduction in suicide mortality due to pesticide self-poisoning. Country-specific data on overall suicide rates were obtained for the year 2017 by age and sex from the Global Burden of Disease Study 2017 (GBD 2017) Data Resources. Overall suicide rates for

For the Global Burden of Disease  
Study 2017 Data Resources see  
<http://ghdx.healthdata.org/gbd-2017>



2018–2117 were estimated on the basis of projections of historical trends in suicide rates between 1990 and 2017, as seen in GBD 2017 (appendix pp 12–13). The pesticide suicide rate was subsequently estimated by multiplying the overall suicide rate by the proportion of suicides due to pesticide self-poisoning. Data on the proportion of suicides due to pesticide self-poisoning were estimated for the year 2017 based on the availability either of country-specific data from the WHO mortality database or nationally representative studies,<sup>19,28,29</sup> or of WHO regional estimates from a previous review<sup>2,27</sup> when country-specific data were not available (table 1). Proportion estimates for 2018–2117 were based on projections that accounted for declining trends in the percentage of the total working population employed by the agricultural sector (appendix pp 12–13).<sup>34</sup> The effect of means substitution was accounted for by modelling marginal increases in the non-pesticide suicide rate, which were based on long-term trends following successive bans of highly hazardous pesticides in Sri Lanka.<sup>17,35</sup> Several equations were derived to calculate post-intervention health effects using the three input parameters for which there were available data: the overall suicide rate; the proportion of suicides attributable to pesticide self-poisoning; and the intervention effect size applied to the pesticide suicide rate. These equations were applied to each age-sex cohort in the model to estimate overall suicide rates, pesticide suicide rates, and mortality rates that occur post-intervention (appendix p 14).

Intervention health effects were summarised using HLYGs, which are equivalent to averted disability-adjusted life-years (DALYs), which in turn are made up of years of life lost (YLLs) and years lived with disability (YLDs). YLLs were estimated for each age-sex cohort by taking the number of deaths in a particular year and multiplying this by potential YLLs. Potential YLLs were calculated as the lowest value of either the difference between the current age of the cohort and the average life expectancy in the country, or the difference between the current age of the cohort and the remaining time before the end of the 100-year model time horizon. YLDs were estimated for each age-sex cohort by calculating the total number of non-fatal pesticide suicides occurring in a particular year, multiplying this by the duration of ongoing disability attributable to pesticide self-poisoning, and then further multiplying this by the GBD 2017 disability weight for acute short-term poisoning of 0.16 (95% CI 0.11–0.23). Both YLLs and YLDs were adjusted to account for background morbidity due to other diseases. Further details on health effect modelling are in the appendix (pp 7–11).

### Costing and cost-effectiveness analysis

We used the costing framework and methods developed by WHO-CHOICE to estimate the country-specific costs of highly hazardous pesticide bans.<sup>25</sup> We estimated country-specific intervention costs using previous costing templates developed by WHO to evaluate NCD

prevention and control policies and interventions.<sup>36,37</sup> Previous NCD costing templates were modified to account for the different stages in implementing national bans on highly hazardous pesticides, which were characterised by significant upfront costs for the initial, one-off enactment of relevant legislation, and ongoing enforcement costs lasting up to 10 years following the ban's enactment. Further details on the costing analysis are in the appendix (p 15).

The main outcome for the base case analysis was the average cost-effectiveness ratio, expressed as the total intervention cost (2017 I\$) divided by the total HLYGs relative to no intervention. Health interventions with a cost-effectiveness ratio less than \$100 per HLYG have previously been identified as being very cost-effective (ie, value for money) in LMICs. This threshold for cost-effectiveness aligns with that used by previous cost-effectiveness analyses by WHO to identify so-called best buys in addressing the global burden of NCDs.<sup>37</sup>

### Uncertainty analysis and sensitivity analysis

We did an uncertainty analysis to quantify the effect of input parameter uncertainty on the final cost-effectiveness results. Input parameter uncertainty comprised either sampling error around a particular estimate (eg, standard error), or a range of plausible values for a particular input parameter based on expert opinion or evidence from the literature. Ersatz software (version 1.31; Brisbane, Australia) was used to run Monte Carlo simulation with 1000 iterations and produce results with 95% uncertainty intervals (95% UIs). We did univariate deterministic sensitivity analyses to test how cost-effectiveness ratios in the base case analysis would change following a 10% increase or decrease in the mean value of each input parameter (539 in total) when varied one-by-one. We did multivariate probabilistic sensitivity analyses to analyse the strength of association (measured using Spearman's rank correlation coefficient) between each input parameter on the resulting cost-effectiveness ratio, while simultaneously accounting for interactions between other input parameters. The univariate and multivariate sensitivity analyses both aim to determine which input parameters have the greatest effect on the resulting cost-effectiveness ratio. They highlight which input parameters need to be estimated with greater precision to reduce uncertainty around the final result. An additional sensitivity analysis examined how cost-effectiveness ratios would change after applying different annual discount rates to health effects (ie, 3% and 6% instead of 0%) and intervention costs (ie, 0% and 6% instead of 3%). We also did a threshold analysis to examine the effect of incrementally reducing the 5-year intervention effect size from 0% (RR 0.65) to 100% (RR 1.00).

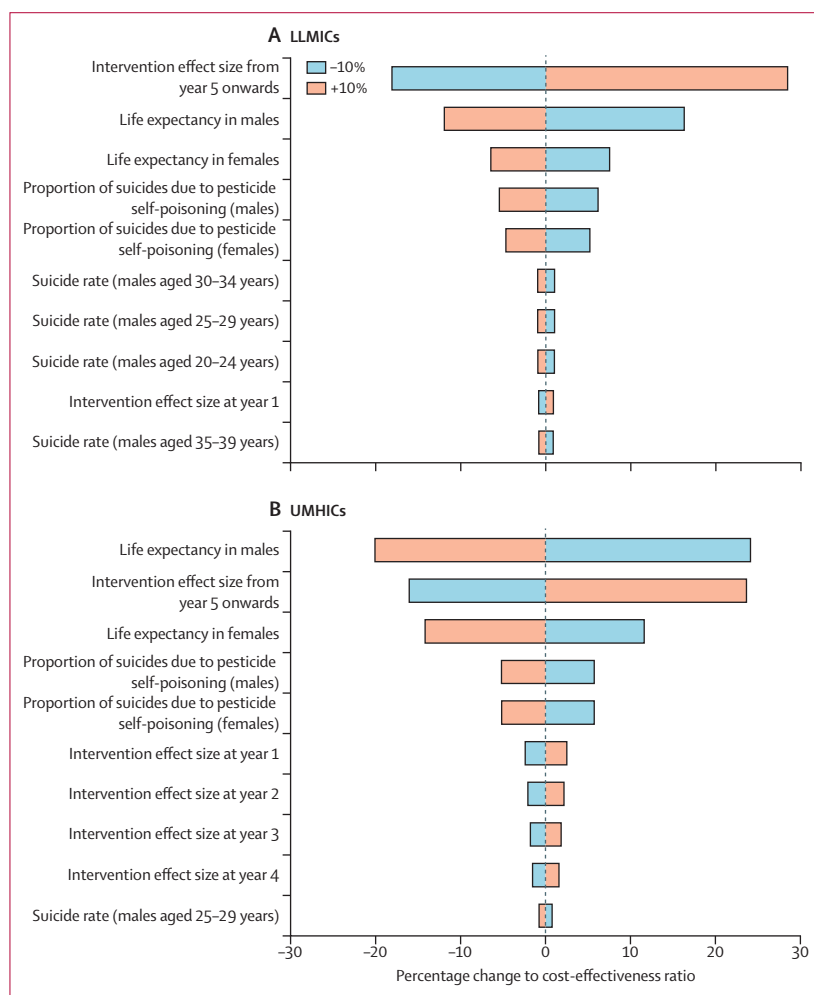
### Role of the funding source

The funders of the study had no role in the study design, data collection, data analysis, data interpretation, or

	Population in 2017, millions	Cost-effectiveness ratio, I\$ per HLYG	Intervention costs, I\$ per 1 million population per year	HLYG, per 1 million population per year
<b>Country income group</b>				
LLMICs (n=9)	2476	\$94 (73–123)	\$7675 (6931–8389)	81.77 (63.29–101.99)
UMHICs (n=5)	1762	\$237 (191–303)	\$6008 (5237–6709)	25.33 (20.20–30.97)
<b>Suicides due to pesticides</b>				
2–9% (n=5)	571	\$699 (515–940)	\$10769 (9787–11776)	15.42 (11.65–20.87)
10–19% (n=3)	429	\$598 (449–796)	\$8383 (7439–9363)	14.02 (10.59–17.68)
20–29% (n=4)	471	\$213 (168–281)	\$8224 (7318–9059)	38.66 (29.33–47.73)
>30% (n=2)	2767	\$75 (58–99)	\$5762 (5012–6550)	77.07 (60.43–97.86)

Data are n (95% uncertainty interval). Costs are in 2017 I\$. I\$=international dollars. HLYG=healthy life-years gained. LLMICs=low-income and lower-middle-income countries. UMHICs=upper-middle-income and high-income countries.

**Table 2: Population-standardised results for the base case analysis**



**Figure 3: Tornado graphs for the univariate deterministic sensitivity analysis for LLMICs (A) and UMHICs (B)**  
LLMICs=low-income and lower-middle-income countries. UMHICs=upper-middle-income and high-income countries.

writing of the report. All authors had full access to the full data in the study and accept final responsibility for the decision to submit for publication.

## Results

An exploratory analysis using the model found that enacting national bans of highly hazardous pesticides across the 14 countries would incur a total cost of \$29.6 million (95% uncertainty interval [UI] 26.3–32.6) or \$0.007 per capita (95% UI 0.006–0.008) and could result in up to 361000 (95% UI 307000–419000) fewer suicide deaths by 2030 or about 28000 (95% UI 24000–32000) each year. This decrease equates to a potential 6.5% (95% UI 5.5–7.4) reduction in suicide deaths among these 14 countries by 2030—ie, about 20% of the one-third target for SDG 3.4. The intervention cost for national bans of highly hazardous pesticides was lower than the cheapest treatment interventions for common mental disorders, also estimated using WHO-CHOICE methods (ie, basic psychosocial support for depression and anxiety, which cost \$0.115–0.159 per capita).<sup>23</sup>

In the population-standardised results for the base case analysis, bans of highly hazardous pesticides were found to be highly cost-effective in LLMICs, with a cost-effectiveness ratio below the threshold of \$100 per HLYG (table 2). The analysis by country income group produced cost-effectiveness ratios of \$94 per HLYG (95% UI 73–123) across LLMICs, and \$237 per HLYG (95% UI 191–303) across UMHICs. Bans were also found to be more cost-effective among countries with a greater proportion of suicides due to pesticides. For example, two countries with proportions of more than 30% (one LLMIC and one UMHIC) together produced a cost-effectiveness ratio of \$75 per HLYG (95% UI 58–99; table 2). The absolute results, which were not population-standardised, are in the appendix (pp 16–18), alongside detailed breakdowns of YLDs, YLLs, and the total number of pesticide suicides averted (in absolute and population-standardised units). Overall, HLYGs were observed to be mostly attributable to mortality impacts (99.7% from YLLs averted) instead of morbidity impacts (0.3% from YLDs averted).

The univariate sensitivity analysis for LLMICs and UMHICs in figure 3 outline the top ten input parameters (out of a total of 539) that led to the largest change in the cost-effectiveness ratio following a 10% change to the mean input value. Cost-effectiveness ratios diverged by more than 10% from the base case result when changing the 5-year intervention effect size and the life expectancy of males or females. The remaining 529 input parameters not displayed in figure 3 changed the cost-effectiveness ratio by less than 0.8%. The results of the multivariate sensitivity analysis are in the appendix (p 19). The 5-year intervention effect size was strongly correlated with the cost-effectiveness ratio, with weak correlations observed for the remaining 538 input parameters (appendix p 19). Cost-effectiveness ratios were highly sensitive to changes in the annual discount rate applied to health effects (table 3). For example, the cost-effectiveness ratio more than doubled when applying a 6% discount rate to health

	Baseline*, I\$ per HLYG	Health effects 3%, I\$ per HLYG	Health effects 6%, I\$ per HLYG	Intervention costs 0%, I\$ per HLYG	Intervention costs 6%, I\$ per HLYG
<b>Country income group</b>					
LLMICs (n=9)	\$94 (73–123)	\$179 (139–233)	\$280 (218–376)	\$108 (84–139)	\$83 (64–113)
UMHICs (n=5)	\$237 (191–303)	\$339 (270–432)	\$456 (365–596)	\$271 (215–337)	\$211 (167–273)
<b>Suicides due to pesticides</b>					
2–9% (n=5)	\$699 (515–940)	\$1650 (1198–2219)	\$2934 (2074–3910)	\$799 (582–1079)	\$614 (441–823)
10–19% (n=3)	\$598 (449–796)	\$995 (761–1327)	\$1480 (1109–1981)	\$685 (506–892)	\$529 (398–696)
20–29% (n=4)	\$213 (168–281)	\$496 (392–652)	\$886 (696–1160)	\$244 (192–321)	\$189 (148–247)
>30% (n=2)	\$75 (58–99)	\$131 (102–174)	\$197 (154–259)	\$86 (66–113)	\$67 (52–88)

Data are n (95% uncertainty interval). Costs are in 2017 I\$. I\$=international dollars. HLYG=healthy life-years gained. LLMICs=low-income and lower-middle-income countries. UMHICs=upper-middle-income and high-income countries. \*The baseline scenario applied a discount rate of 0% to health effects and 3% to intervention costs.

**Table 3: Cost-effectiveness ratios from sensitivity analysis applying different discount rates to health effects and intervention costs**

effects (table 3). The results of the threshold analysis are in the appendix (pp 20–21). Cost-effectiveness ratios were generally stable and remained below \$500 per HLYG after a 63% reduction in the 5-year intervention effect size (RR 0.87) among LLMICs and a 41% reduction (RR 0.79) among UMHICs.

## Discussion

To our knowledge, this study is the first to develop an exploratory model examining the cost-effectiveness of implementing national bans of highly hazardous pesticides across a range of countries. National bans were potentially highly cost-effective when delivered across nine LLMICs. Additionally, such bans appeared highly cost-effective among two countries with the highest proportion of suicides (>30%) attributable to pesticide self-poisoning. These results should, however, be interpreted with caution due to limitations around the underlying input data and assumptions (eg, use of observational data to inform the intervention effect size). The main health effect arising from a national ban on highly hazardous pesticides was the reduction in premature deaths. This was shown by the overwhelming majority of HLYGs being attributable to mortality impacts instead of morbidity. The short duration of ongoing disability following a non-fatal suicide attempt using highly hazardous pesticides (<2 weeks) could be considered of less consequence when compared to the potential YLLs following a death involving pesticide self-poisoning. Bans of highly hazardous pesticides might also provide additional benefits to farmers' health, the environment, and the economy.<sup>4</sup> These benefits include reducing long-term occupational exposure, reducing accidental poisonings among adults and children, reducing contamination of crops and water supplies, preventing unintentional extermination of natural predators, and lowering health-care expenditures due to fewer hospitalisations. Nevertheless, monitoring and evaluation systems should be established to measure changes in agricultural productivity, alongside other adverse effects that could counteract the aforementioned benefits.

Based on these model estimates, national bans of highly hazardous pesticides rank as an affordable and cost-effective intervention when compared with other mental health interventions analysed using WHO-CHOICE methods.<sup>24</sup> The current economic evaluation is among the first to examine the cost-effectiveness of implementing a population-based, suicide prevention intervention in LMICs, with previous economic evaluations having only been published in high-income country settings.<sup>38</sup> The current economic evaluation produced cost-effectiveness ratios of a similar order of magnitude to an Australian cost-utility analysis of responsible media reporting (\$122 per DALY)<sup>39</sup> and a US cost-utility analysis of a suicide prevention and intervention programme implemented in Native American jurisdictions (\$556 per quality-adjusted life-year [QALY]), when converted to 2017 I\$.<sup>40</sup> Conversely, cost-effectiveness ratios were lower than a UK cost-utility analysis of delivering suicide awareness education to general practitioners (\$4760 per QALY)<sup>41</sup> and a US cost-effectiveness analysis of a suicide barrier on the Golden Gate Bridge in San Francisco (\$5124 per person-year saved).<sup>42</sup>

Our findings provide indicative evidence for countries to consider enacting national bans on highly hazardous pesticides within their borders. The enactment of such bans is an important strategy to produce substantial reductions in suicide mortality among countries with high proportions of pesticide suicides, facilitating their achievement of SDG target 3.4. However, caution should be applied when translating the results of this analysis to the country level because any prospective bans should account for important local factors that will influence the acceptability, feasibility, and cost-effectiveness of the intervention. For example, countries that allow the common usage of highly hazardous pesticides with very high case fatalities (eg, paraquat [case fatality >50%], aluminium phosphide [>50%], and monocrotophos [>20%]) will accrue the greatest benefit from a national ban of these pesticides. Careful consideration should also be given to the potential effect of national bans on agricultural productivity and the farm-level cost of



production, as has been done in countries that have already implemented bans,<sup>43</sup> noting that effective alternative pesticides with lower lethality will often be available. The economic model developed by this study could be used to inform country-level analyses after tailoring the model to account for relevant local factors and incorporating country-specific data. Although providing detailed policy recommendations is beyond the scope of this study, both WHO, FAO, and other international partners have published advice on how governments can take steps to phase out highly hazardous pesticides within their respective countries.<sup>4-6</sup>

There are several limitations to this study. First, the use of observational data to inform the intervention effect size (a key input parameter) could bias the cost-effectiveness findings. A threshold analysis was done to explore the potential effect of this bias, although the results could be improved as more precise data becomes available. This limitation also applies to other input parameters, which were often based on imperfect data or assumptions that could be improved upon, or both. Second, there were issues around the availability of accurate or reliable country-specific data. This was especially the case when estimating the proportion of suicides attributable to pesticide self-poisoning and where regional estimates were used as a proxy in the absence of country-specific data. Third, we did a multi-country analysis using comparable methods across various country contexts, which might limit generalisability. Fourth, WHO-CHOICE methods do not incorporate the potential effect of out-of-pocket expenditures (particularly catastrophic health expenditures), health-care cost savings, and productivity gains. Fifth, aggregate results for LMICs and UMHICs were calculated by summing absolute intervention costs and absolute HLYGs across relevant countries in each country income group, and consequently dominated by countries with large populations (ie, India in the LMICs and China in the UMHICs). The aggregate cost-effectiveness results presented here will consequently mask heterogeneous results at the individual country level. Sixth, survivors of suicide attempts are at an increased risk of all-cause mortality.<sup>44</sup> Banning highly hazardous pesticides will probably increase the number of non-fatal suicide attempts through the use of less lethal pesticides and medicines, because the majority of people continue to ingest poisonous substances for self-harm in line with cultural norms. Even so, the model assumed that all-cause mortality remained unchanged, which might bias the results. Seventh, the adoption of the null comparator led to the exclusion of ongoing health-care costs that might occur following a suicide attempt. Self-harm survivors might require aftercare for psychiatric problems that they would not have received if they had died. However, international studies suggest that self-harm in LMICs, where pesticide self-poisoning is common, has a lower association with mental illness

than in high-income countries.<sup>45</sup> This association, alongside high treatment gaps in LMICs (78–86%),<sup>46</sup> suggests that such costs will be modest. Lastly, the use of the null comparator meant that the costing analysis did not account for pre-existing pesticide regulatory infrastructure that controls the sale of pesticides among the 14 countries (ie, pesticide regulations were assumed to be implemented from scratch). Intervention costs might have been overestimated because the marginal cost of enacting pesticide bans will be lower in countries with pesticide regulations already in place than in those where they are not.

This exploratory economic analysis found that national bans of acutely toxic pesticides are a potentially cost-effective and affordable intervention for reducing suicide deaths in countries with a high burden of suicides that are attributable to pesticides. However, the study findings are limited by imperfect data and assumptions that could be improved upon by future studies. More research is required to quantify the assumptions made in this model, including the potential for substitution of means and the effect on agricultural yields.

#### Contributors

YYL, DC, and MvO conceived, planned, and oversaw the study. YYL led the model development, the analysis of intervention costs and health effects, and drafted the paper. ME, DG, and AF contributed technical expertise on the epidemiology of pesticide suicides and the effectiveness of nationwide pesticide bans. YYL, DC, ME, DG, and MYB contributed to the acquisition and verification of data. DC, ME, DG, AF, FK, MYB, CM, RB, DFS, JS, and MvO contributed to the conceptual development of the cost-effectiveness model and its constituent parts. All authors reviewed, commented on, and approved the final manuscript.

#### Declaration of interests

DC, AF, MYB, RB, and MvO are staff members of WHO. ME is a WHO member of the FAO–WHO Joint Meeting on Pesticide Management, and reports receiving an unrestricted research grant from Cheminova (2012) and travel expenses from Syngenta to attend meetings (2005–06). ME, DG, and FK are affiliated with the Centre for Pesticide Suicide Prevention, which is funded by an Incubator Grant from the Open Philanthropy Project Fund, an advised fund of Silicon Valley Community Foundation, on the recommendation of GiveWell, USA. ME, DG, and FK declare relevant grants from the Wellcome Trust and American Foundation for Suicide Prevention, were expert advisers to the WHO consultation on cost-effectiveness of suicide prevention interventions, including pesticide regulation (2019), provided technical assistance for the development and publication of “Suicide Prevention: A Resource Guide for Pesticide Registrars and Regulators” (2019). DG is supported by the National Institute for Health Research Biomedical Research Centre at University Hospitals Bristol and Weston National Health Service Foundation Trust and the University of Bristol. The views expressed in this publication are those of the authors and not necessarily those of the National Health Service, the National Institute for Health Research, or the Department of Health and Social Care. DG also reports grants from WHO, during the conduct of the study, and being a member of the scientific advisory group for a Syngenta-funded study to assess the toxicity of a new paraquat formulation and the scientific advisory group for a pesticide self-storage project funded by Syngenta (between 2003 and 2011), chairing a data monitoring and ethics committee for a Syngenta-funded trial of the medical management of paraquat poisoning, receiving travel costs to attend research Syngenta-funded trial meetings, and being an expert adviser to the first WHO consultation on best practices on community action for safer access to pesticides (2006), all outside the submitted work. FK is a member of the UN DDT expert committee under the Stockholm Convention. The remaining authors declare no competing interests.

# Data sharing

In line with the WHO open access policy, data collected for this study are being made available to others on the Figshare repository through a CC BY 4.0 license at the date of publication, including country-level demographic and epidemiological data, other model parameters relating to intervention costs and effectiveness, and the model structure itself. Application of the CC BY 4.0 license requires interested users of the data to attribute the original source.

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